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(54) Improvements in or relating to the prediction of product defects

(57) A software predictive engine is described that provides a tool to analyze the import of defection the software development process. By providing a prediction of escaping defects, in terms of the normalized sigma measure and the predicted lines of code, together with historical data the impact of defects at the stages of the design can be predicted. As actual defects are measured predicted sigma level can also be predicted. The engine includes generating a defect containment matrix for the historical data and for the current software program being developed.

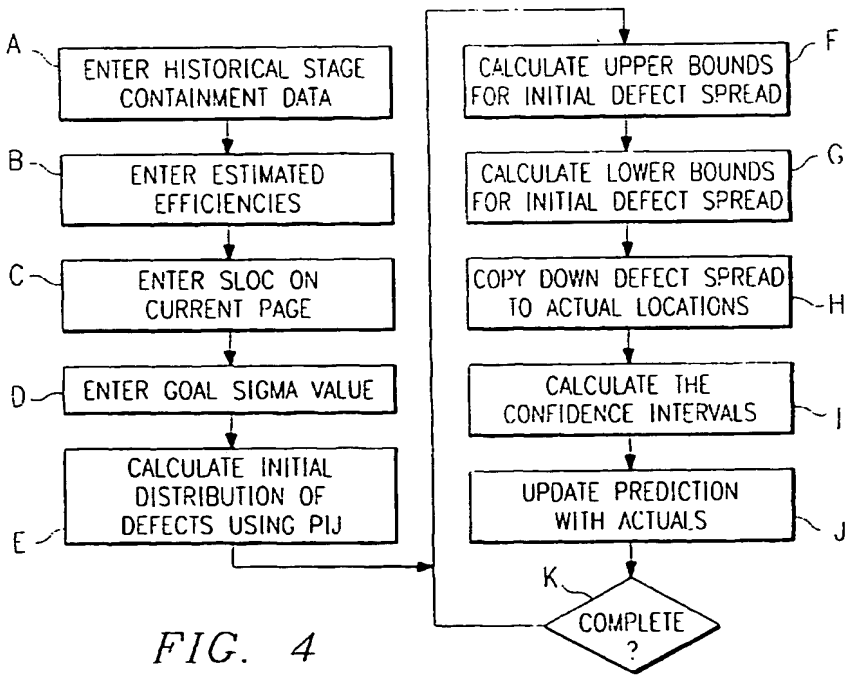

FIG. 4

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Description

TECHNICAL FIELD OF THE INVENTION

This invention is related to a method and apparatus for predicting product defects.

BACKGROUND OF THE INVENTION

Texas Instruments Incorporated Defense Systems and Electronics Group (DSEG), a 1992 Malcolm Baldrige Quality Award Winner, has developed both the technology and deployment infrastructure for a quality initiative named Six Sigma. Aimed at measuring and reducing variation in a product or service, this technology has allowed many Texas Instruments disciplines, including software development, to quantifiably progress towards zero defects. Six Sigma originated with a concept that variation in a product or service is the culprit behind defects. Consequently, one can begin with customer requirements and identify units of product or service in which opportunities for defects and actual defects are itemized. Through simple computations, a sigma level of performance may be identified. Higher sigma values represent higher quality levels. Six Sigma performance is equivalent to no more than 3.4 defects per million opportunities. But why do we care about Six Sigma? In terms of cost of quality, a Four Sigma organization cannot compete with a Six Sigma organization A Four Sigma organization will spend as much as 25% of each sales dollar on cost of non-conformance while a Six Sigma organization will spend less than 1%. Organizations performing at Four Sigma will spend 25 times more dollars on rework, etc. than a Six Sigma organization will. Additionally, Six Sigma analysis supports defect causal analysis, prevention and prediction. It has been incorporated into our process improvement program and is part of a widespread training program for all employees of Texas Instruments DSEG. Over the past 5 years, we believe that this technology contributed to our 10X improvement in software fault density. Six Sigma measurement begins with the customers and their requirements. Defect categories may then be identified along with units of product or service. From this framework, defects per unit, opportunities for defects, defects per million opportunities and sigma levels may be computed. Defects per million opportunities (dpmo) may be computed by simply dividing the defects per unit (DPU) by the opportunity count (source lines of delivered software) and then multiplying by 1 million.

The number of defects per million opportunities (dpmo) may be converted into a Sigma level via use of a conversion chart as shown in Figure 1. Note that changes in the dpmo levels are not linearly proportional to the Sigma levels. Thus, for an organization of higher levels of sigma performance, smaller amounts of dpmo improvement are needed to achieve the same sigma improvement as that of an organization at a lower level of sigma performance. Sigma measures support benchmarking of quality levels.

In the development of software there are generally at least five stages - the first being the requirement stage (RA); the second being the preliminary design stage (PD); the third being the design detail stage (DD); the fourth the coding stage (CUT), and the fifth the integrating and testing stage (I&T). Defects in software development activity represent rework, resulting in increased cost and cycle times.

While it is known to make estimates of escaping defects mode during a latter phase of integration and test using Weibull curve fittings, there is no known solution for long range prediction of the number of escaping defects.

Accordingly, a technical problem to be solved relates to the provision of methods and apparatus which can automatically predict counts of defects as part of a development process.

SUMMARY OF THE INVENTION

In accordance with one preferred embodiment of a present invention, there is provided a method and statistical tool apparatus for predicting defects in products. The method according to one embodiment includes the step of providing historical data of defects at different stages of development and a value representing a goal for escaping defects. Also provided is the planned total number of opportunities for defects. The goal for the number of escaping defects and planed number of opportunities for defects are backsolved to determine the total number of defects. The total defects are distributed as a function of the historical data to provide prediction of defects at the different stages of development.

The apparatus according to one preferred embodiment of the present invention the tool comprises a processor, a memory and a keyboard and a drive for loading a software package and a display. The processor is loaded with a program for storing historical data indicating the historical pattern of defect containment in the stages of development. The processor has stored therein algorithms for computing sigma values based on opportunities and escaping defects in the stages and including an algorithm for backsolving from historical data.

DESCRIPTION OF THE DRAWINGS

Embodiments of the invention are described, by way of example only, with reference to the accompanying drawings. in which:

Fig. 1 is a conversion chart of DPMO to Sigma:

Fig. 2 is a diagram of the personal computer used for the engine according to one embodiment of the present invention:

Fig. 3 is a system diagram according to one embodiment of the present invention:

Fig. 4 is a flow chart of the operation according to one embodiment of the present invention:

Fig. 5 illustrates defect flow analysis:

Fig. 6 illustrates the historical sheet:

Fig. 7 illustrates the current sheet:

Fig. 8 illustrates a summary sheet: and

Fig. 9 illustrates a current sheet with equations embedded therein.

DESCRIPTION OF PREFERRED EMBODIMENT

A Software Sigma process of an embodiment of the present invention stresses defect prevention, monitoring of defect levels, causal analysis for process improvement, and the sigma metric to predict, early in the development cycle, the level of escaping defect delivered with the product. A unique aspect of the statistical model we construct to predict escaping defects is the use of project defect phase containment data in a dual manner. As historical data, phase containment data. converted to conditional probabilities, is used to model the current state of a projects software process's effectiveness to prevent and capture defects. During the development phase, actual phase containment data is captured and utilized to make the prediction of escaping defects from the finished product.

Variation in performance of a quality attribute causes defects. Performance of a quality attribute is often assumed to follow a normal distribution (bell shape curve) which is centered on a given mean (average) value. The potential for defects arises when the tails of the performance curve fall outside given specification limits. Adapted to software, there is no assumption made about distribution normality. In fact, distributions of interest appear to follow Poisson or Weibull distributions.

In accordance with one embodiment of the present invention, a software sigma predictive engine is provided for predicting defects in software. The engine comprises, for example, a personal computer (PC) with a processor 11, a storage unit 13 (such as a disk drive), a monitor 15, and input device 17 such as a keyboard and mouse and 17a as shown in Fig. 2. The processor is loaded with a software spreadsheet program such as Microsoft Excel 5.0. The operation is implemented as a workbook in three sheets. The user enters data in two sheets, the historical sheet 21 and the current sheet 23. See diagram in Fig. 3. A third sheet 27, the summary sheet, automatically summarizes the decisions made. actual observed defects, the predicted number of escaping defects, and statistical confidence intervals qualifying the "goodness" of the prediction. There is also a fourth sheet 29 or page which contains the original computer program to calculate the Poisson probabilities.

Aspects of one embodiment of the present invention are illustrated by the flow chart of Fig. 4. where historical defect containment data is entered (step A) in the cells of Excel 5.0 as a workbook in the historical sheet as a stage defect containment matrix. The user enters historical defect containment data for the various stages of design in a defect containment matrix at cell locations. This is arrived at from previous designs and detections of defects at these stages. Based on estimated efficiency of detection of defects, the inspection efficiencies are calculated (step B) and copied to the second sheet or page called the current sheet 27. The estimated overall efficiency of the process to detect DPU of each type over all stages is entered. The number of software lines of code (SLOC) is entered on the current workbook sheet 25 (step C) and the goal sigma value is entered on the current workbook sheet 25 (step D). Each SLOC represents a defect opportunity. Based on the goal sigma values and lines of code (SLOC) entered the total number of observed defects are calculated. The initial distribution of these defects is calculated using probability P_{ij} (step E) of a defect in ith step of being detected and removed in jth step. The upper bounds for initial defect spread

is calculated (step F) and the lower bounds for initial defect spread is calculated (step G). The defect spread is copied down to the actual locations in the current sheet (step H) . The confidence interval is then calculated (step I). The statistical model used views the number of defects generated in each stage as Poisson random variables which are independent between the different stages of the development process. These random numbers of defects are then subjected to the random process of defect detection and the resulting number of detected, and undetected, defects are random variables whose distributions remain Poisson. The total number of detected defects, as well as the total number of escaping defects, then can be represented as the sum of independent Poisson random variables and it is this that makes it possible to develop an unbiased estimator for the mean number of escaping defects. An estimate of the variance of the estimator, along with the asymptotic normality of its distribution, allows for the calculation of an approximate statistical confidence interval for the mean number of escaping defects, as well as an approximate prediction interval for the actual number of escaping defects. These estimates and intervals are automatically calculated and displayed in the spreadsheet, along with corresponding estimates and intervals for the process sigma level. The initial prediction is up-dated (step J) with actual data until all actuals have been entered (step K). As the design progresses and actual defects are measured the actual defects are compared to the error bounds to determine if there is consistency between the data and the model and to see if the sigma goal will be reached.

Referring to Figure 5, there is illustrated the defect flow analysis for a software design project which starts with RA as a requirement and proceeds to the second Step PD, which is preliminary design, which proceeds to a detailed design (DD) which then proceeds to actual generation of code (CUT) and then to the fifth step of integration and test (I&T). Fig. 5 indicates the defect data flow model used to estimate the number of escaping defects for a typical software product. Some of the final defects from the requirements (RA) escape through the preliminary design, the detailed design, the coding and integration and test. Likewise some uncorrected defects in the preliminary design (second line) escape and pass on to detailed design, through the coding, and through integration and test. Some defects at the detailed design escape through coding and integration and test. Some coding errors escape through integration and test. Some integration and test errors escape. The total escaped defects per million opportunities is the defects per million opportunities (dpmo) which is converted to the Sigma level.

The historical sheet shown in Fig. 6 is the primary location for loading historical data to prime the pump in preparation for the collection of actual defect data during the project. The primary software sigma measure is defects per unit (DPU). When we associate opportunities and a chance for non-conformance, we are providing a measure of complexity that allows us to compare products of different size. The use of opportunities as a common denominator to compute defects per million opportunities (dpmo) is a way to normalize the different sizes between both intermediate and final product. Enter in cells C4:G8 of Excel 5.0 historical workbook sheet the defects for each stage observed from historical data or best engineering judgement. This data represents the pattern of defects detected across the project phases. For example the defects originated at requirements stage RA and detected at RA is 30. The defects detected at Integration and Test originated 1 and RA, 1 at PD, 5 at DD, 17 at CUT, and 3 at I&T. It represents the pattern most likely to occur and is transformed into conditional probabilities in cells C15:G19 labeled "inspection efficiencies". These probabilities are automatically calculated in cells C15:G19 of the historical sheet and are copied onto the current and summary sheets. Represented as percentages, these are the conditional probabilities that a defect generated in a prior or same stage will be observed in the current stage. For example, the total RA defects is 64 and the defect at C4 is 30 so the percentage is 30/64 X 100% = 47. These percentages are then derated by the estimated efficiencies. The percentages listed represent de-rating of perfect capture which the conditional probabilities would suggest. In fact, the conditional probabilities are adjusted by the estimated efficiency percentages to indicate that our observations are not 100% efficient. These multipliers may be estimated for programs with complete data, but without that one must use best engineering judgement. The spreadsheet shown in Fig. 6 has these values preset at 95% for requirements DPU, 94% for preliminary design defects, 93% for detailed design defects, 92% for code and unit test and 90% for integration and test. Screening effectiveness percentages are conditional probabilities estimated from historical stage containment data and may be revised.

The initial values in the current sheet (Fig. 7) allow the developer to model his environment and the effect in terms of DPU for given values of screen effectiveness and assumed sigma for the product. As actual data is entered for each phase, it overrides the DPU computed by the spreadsheet, which were needed to obtain the assumed goal sigma. From this point in time forward, to improve the product's sigma it is necessary to reduce the DPU observed at each stage by improved software process steps. The screen detection probabilities may be increased by improving the screens ability to detect both in-stage and out-of-stage DPU. The process is improved by finding most DPU in early stages of development.

The product name, delivered SLOC (Software Lines of Code) and goal sigma are entered at E4 and E5 in the shaded blocks at the top of the current sheet illustrated in Fig. 7. Note that the goal sigma may be based upon Fault Density Data of similar products or be the development goal the project expects to attain.

The DPU count by percentage in the historical sheet based on defects observed are computed and copied to in the current sheet. These percentages are used to spread the DPU in the following cells with planning DPU spread by

stage. The percentages may be adjusted to reflect engineering judgement if required.

Using the percent spread, knowledge of the goal sigma of E5, the delivered SLOC E4 and the probabilities of detection, the engine back calculates the DPU needed in each phase to reach the sigma goal. These DPU are copied to the cells (C51. G55) called "defects observed" where actuals will overwrite these estimates as they are received. Note that the number of DPU passed to the next phase and the number generated (greater than observed) are also indicated below these cells. First the total DPU are calculated from the sigma value and SLOC and then based on percentage in C10:G14. The initial values in C51:G55 are entered. This predictive framework is based on assumptions.

Assume a process has N steps or stages. In step i, L_i defects are introduced. Assume L_i has a Poisson distribution with mean λ_i and that L_i and L_j are independent for $i \neq j$. Assume also that a defect introduced in the ith step has a probability P_{ij} of being detected and removed in the jth step, $j \geq i$, and that the detection of defects forms a Bernouli process and the detection of one defect is independent of the detection of other defects. It can be shown that the number of defects detected in stage, K_{ii}, has a Poisson distribution with mean $\lambda_i P_{ii}$ and that the number of defects escaping from the stage they were introduced, $L_i - K_{ii}$, has a Poisson distribution with mean $\lambda_i(1-P_{ii})$. Furthermore. it can be shown that these random variables are independent.

This leads to the fact that the numbers of defects of a specific origin, found in each stage, have Poisson distributions and are all independent of each other. Since the number of defects which escape from step i to step i+1, $L_i - K_{ii}$, has a Poisson distribution with mean $\lambda_i(1-P_{ii})$, and since these defects each have a probability P_{ii+1} of being detected, the number of stage i defects detected in step i+1, K_{ii+1}, has a Poisson distribution with mean $(1-P_{ii})P_{ii+1}\lambda_i$. In general, the number of step i defects detected (and removed) in the jth step is given by K_{ij} and has a Poisson distribution with mean $(1-P_{ii})\,(1-P_{ii+1})\ldots(1-P_{ij-1})P_{ij}\lambda_i$. Furthermore, these K_{ij} are all independent. In addition, since they are simply the sum of independent Poisson variables, the total number of defects detected in each stage, the total number of detected defects introduced at each stage, and the total number of escaping defects all have Poisson distributions. Let

$$L^*_i = L_i \sum_{j=i}^{N} K_{ij}$$

be the number of step i defects which have not been detected after the Nth step. By induction, it can be shown that L_i^* has Poisson distribution. The mean of L_i^* is given by

$$\lambda_i^* = \lambda_i \prod_{j=i}^{N}(1 - P_{ij}) = \lambda_i(1 - P_{ii})(1 - P_{ii+1})\ldots(1 - P_{iN}) = a_i \lambda_i$$

where

$$a_i = \prod_{j=i}^{N}(1 - P_{ij})$$

Let

$$L^* = \sum_{i=1}^{N} L^*_i$$

be the total number of escaping defects. Since the L_i^* are independent Poisson variables, L^* has a Poisson distribution with mean

$$\lambda^* = \sum_{i=1}^{N} \lambda_i^* = \sum_{i=1}^{N} \lambda_i \prod_{j=i}^{N}(1 - P_{ij}) = \sum_{i=1}^{N} a_i \lambda_i$$

ESTIMATORS

As stated before, the K_{ij} are independent, Poisson variables with means

$$(1 - P_{ii})(1 - P_{ii+1})\ldots(1 - P_{ij-1})P_{ij}\lambda_i = \frac{a_i P_{ij}\lambda_i}{b_{ij} = \prod_{k=j}^{N}(1 - P_{ik})} = \frac{a_i P_{ij}\lambda_i}{b_{ij}}$$

where

$$b_{ij} = \prod_{k=j}^{N}(1 - P_{ik})$$

This means that

$$K_{i.} = \sum_{j=i}^{N} K_{ij}$$

the total number of defects from stage i which were detected, has a Poisson distribution with mean and variance given by:

$$E(K_{i.}) = a_i\lambda_i \sum_{j=i}^{N} \frac{P_{ij}}{B_{ij}}$$

and

$$Var(K_i) == a_i\lambda_i \sum_{j=i}^{N} \frac{P_{ij}}{b_{ij}}$$

The $K_{i.}$ also form a sufficient statistic for estimating the λ_i. and hence the λ_i^* and λ^*.

The maximum likelihood estimators (MLE) for the λ_i are given by

$$\hat{\lambda}_i = \frac{K_i}{a \sum_{j=i}^{N} \frac{P_{ij}}{b_{ij}}}$$

and this the MLE for λ^* is given by

$$\hat{\lambda}^* = \sum_{j=i}^{N} \hat{\lambda}_i^* \sum_{j=i}^{N} a_i\hat{\lambda}_1 = \frac{K_i}{a \sum_{j=i}^{N} \frac{P_{ij}}{b_{ij}}}$$

Since

$$E(\hat{\lambda}^*) = \sum_{j=i}^{N} a_i \lambda_i = \lambda^*$$

$\hat{\lambda}^*$ is also an unbiased estimator of λ^* with variance given by.

$$Var(\hat{\lambda}^*) = \sum_{j=i}^{N} \frac{Var(K_i)}{(\sum_{j=i}^{N} \frac{P_{ij}}{b_{ij}})^2} = \sum_{j=1}^{N} \frac{a_i \lambda_i}{\sum_{j=i}^{N} \frac{P_{ij}}{b_{ij}}}$$

which can be estimated by

$$Var(\hat{\lambda}^*) = \sum_{i=1}^{N} \frac{K_i}{(\sum_{j=i}^{N} \frac{P_{ij}}{b_{ij}})^2}$$

For the above software development/inspection process N=5. Thus

$$a_1 = (1-P_{11})(1-P_{12})(1-P_{13})(1-P_{14})(1-P_{15})$$

$$a_2 = (1-P_{22})(1-P_{23})(1-P_{24})(1-P_{25})$$

$$a_3 = (1-P_{33})(1-P_{34})(1-P_{35})$$

$$a_4 = (1-P_{44})(1-P_{45})$$

$$a_5 = (1-P_{55})$$

$$\lambda^* = a_1\lambda_1 + a_2\lambda_2 + a_3\lambda_3 + a_4\lambda_4 + a_5\lambda_5$$

and

$$\hat{\lambda}^* = \frac{K_i}{a_i \sum_{j=i}^{5} \frac{P_{ij}}{b_{ij}}}$$

with

$$\hat{\lambda}^* = a_1\hat{\lambda}_1 + a_2\hat{\lambda}_2 + a_3\hat{\lambda}_3 + a_4\hat{\lambda}_4 + a_5\hat{\lambda}_5$$

$$= \frac{K_1}{\sum_{j=1}^{5} \frac{P_{1j}}{b_{1j}}} + \frac{K_2}{\sum_{j=2}^{5} \frac{P_{2j}}{b_{2j}}} + \frac{K_3}{\sum_{j=3}^{5} \frac{P_{3j}}{b_{3j}}} + \frac{K_4}{\sum_{j=4}^{5} \frac{P_{4j}}{b_{4j}}} + \frac{K_5}{\frac{P_{55}}{b_{55}}}$$

$$\hat{Var}(\hat{\lambda}^*) = \frac{K_1}{(\sum_{j=1}^{5} \frac{P_{1j}}{b_{1j}})^2} + \frac{K_2}{(\sum_{j=2}^{5} \frac{P_{2j}}{b_{2j}})^2} + \frac{K_3}{(\sum_{j=3}^{5} \frac{P_{3j}}{b_{3j}})^2} + \frac{K_4}{(\sum_{j=4}^{5} \frac{P_{4j}}{b_{4j}})^2} + \frac{K_5}{(\frac{P_{55}}{b_{55}})^2}$$

The block of cells C31:G35 are the upper limits and these are calculated based upon Poisson probability tails. The numbers represent upper bounds for actual DPU counts entered in the defects observed block or cells. The probability that one of the actual DPU values is greater than the corresponding upper bound cell, given our historical assumptions, is at most Alpha_U. In other words, there is at most an Alpha_U x 100% chance that an actual number of defects will exceed the corresponding upper limit, given true historical assumptions. If several actuals, say n, exceed their corresponding upper bounds, then there is at most an $(Alpha\_U)^n$ x 100% chance that the historical assumptions are correct. To reject the historical assumptions there are two alternatives hypothesis:

First, the DPU may exceed expected results due to superior process which is finding more DPU.

Second, the process is not as effective at preventing DPU from occurring in the process, resulting in more defects to be found.

Only experienced engineering judgement can determine the correct conclusion. In any case, the DPU escaping and product sigma will be lower than the initial goal. A fourth page in Excel Macros contains the original computer programs to calculate Poisson probabilities. See appendix A for the Macros.

The block of cells C41:G45 are lower limits are calculated based upon Poisson probability tails. The numbers represent lower bounds for actual DPU counts entered in the defects observed block of cells. The probability that one of the actual DPU values is less than the corresponding lower bound, given our historical assumptions, is at most Alpha_L. To reject the historical assumptions there are two alternative hypothesis:

First, the DPU may be less than expected due to an inferior inspection process which is finding fewer defects than expected.

Second, the process is more effective than expected at preventing defects from occurring in the process, resulting in fewer defects to be found.

Only experienced engineering judgement can determine the correct conclusion.

The block of cells C51:G55 is initialized to the planning DPU spread by stage. As actual DPU data is collected by the project, it is entered to overwrite this data. Finally, the data contains only actual data and based upon actual data observed, the sigma of escaping DPU is calculated.

The confidence level E58 represents the probability that the true values of DPU, dmpo, and sigma in the corresponding cells are within the upper and lower bounds indicated. The sigma interval labeled in this program represents a confidence interval predicting the sigma for escaping DPU based upon this programs actual data. The interval labeled average represents a confidence interval based upon repeating the experiment of collecting actuals multiple times for this program. The estimator can be used to generate an approximate confidence interval for the mean number of escaping defects, as well as an approximate prediction interval for the actual number of escaping defects.

The first block of cells in the Summary page as illustrated in Fig. 8 reminds the reviewer of the historical stage containment data which has been used to model process effectiveness at defect observation. The second block of cells represents the data set of actual stage containment DPU for the current project. This data resulted from overwriting the planning DPU spread on the current sheet into the defects observed block. The confidence level set on the current page is copied to the summary page. It represents the probability that the true values of DPU, dpmo, and sigma in the corresponding cells are within the upper and lower bounds indicated. The sigma interval labeled in this program represents a confidence interval predicting the sigma for escaping DPU based upon this programs actual data. The interval labeled average represents a confidence interval for the long-term average DPU level for all projects with the same defect generation and inspection characteristics.

In Fig. 9 there is illustrated a current sheet with equations behind the cells. Cells C81:G86 calculate the total defects. The Poisson upper limits are cells C31:G35. The Poisson lower limits are in cells C41:G45.

Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the scope of the invention.

For example, although an embodiment of the invention has been described in which various functions are imple-

mented by software, it will be appreciated that in other embodiments, at least some of those embodiments can be implemented in hardware (for example using an ASIC).

Claims

1. A method of automatically predicting product defects of a future product the method comprising the steps of:

storing in a first database historical data of defects at different stages of development from a past product and a value representing corresponding escaping defects:
providing a first signal representing a first value of a predicted number of opportunities for defects and a second signal representing a second value of planned defects per opportunities for said future product:
backsolving in processing means said first and second values represented by said first and second signals to provide a third signal representing total predicted defects:
generating a second database of predictive defects at different stages of development for said future product as a function of said first database historical data and said first and second signals: and
displaying said predictive defects at different stages of development for said future product.

2. The method of claim 1 wherein said method is for predicting software defects and said predictive opportunities for defects are the number of software lines of code.

3. The method of claim 2 wherein said value representing escaping defects is a sigma value dependent on DPMO.

4. The method of claim 2 including the steps of changing the number of defects in said second database for the different stages from predictive defects to actual defects as actual defects are detected, producing a fourth signal representing defects based on actual and predictive defects.and displaying said defects based on actual and predictive results.

5. The method of claim 1 wherein said value representing escaping defects is a sigma value dependent on DPMO.

6. The method of claim 1 including the steps of changing the number of defects in said second database for the different stages from predictive defects to actual defects as actual defects are detected, producing a fourth signal representing defects based on actual and predictive defects.and displaying said defects based on actual and predictive results.

7. An automated method of software defect prediction of a future project, the method comprising the steps of:

constructing project phase defect containment data from past one or more projects and quality level in terms of escaping defects and converting said project containment data to conditional probabilities :
providing a first signal representing software lines of code and a second signal representing quality level in terms of escaping defects:
generating a second database of predictive defects at different stages of development for said future product as a function of said conditional probabilities and said first and second signals: and
displaying said predictive defects at different stages of development for said future product.

8. The method of claim 7 including the steps of changing the number of defects in said second database for the different stages from predictive defects to actual defects as actual defects are detected, producing a fourth signal representing defects based on actual and predictive defects.and displaying said defects based on actual and predictive results.

9. A method of predicting software defects in a computer program, the method comprising the steps of:

automatically generating and displaying on a display means a historical sheet and a current sheet for providing data representing defects at different stages of software design:
entering in said historical sheet data representing defects at different stages of design and sigma value corresponding thereto based on previous designs:
entering estimated efficiencies of said historical data:
responding to said entered data automatically to generate and to display a distribution of defects based in

efficiencies:
entering proposed number of lines of code and signal value for current code to be predicted:
backsolving said sigma value and said lines of code to provide a count of total defects and distributing said defects based on said percentage of distribution of defects and providing on said current sheet and displaying said current sheet:
calculating upper bounds for initial defect spread:
displaying said upper bounds for observed defect spread:
calculating lower bounds for initial defect spread: and
displaying said lower bounds for observed defect spread.

10. Apparatus for automatically predicting software defects comprising:

storage means for storing historical data of defects at different stages of software development:
calculating means coupled to said storing means for calculating a sigma value:
processing means coupled to said storing means and calculating means for displaying said historical data and said sigma value:
means responsive to entry of a new sigma value for backsolving said sigma value to provide predictive defects at different stages of software development.

11. A software defect predictive engine comprising:

a processor:
a first computer storage for storing under program control first electrical signals representing historical data on defects at different stages of a software design:
said processor being responsive to said first electrical signal and estimated prediction efficiencies for providing second signals representing the spread of defects at the different stages:
a second computer storage for storing current data relative to software being predicted:
said processor being arranged, in response to lines of code entered and sigma value entered, to calculate and provide electrical signals representing total defects projected and being responsive to said second electrical signals to calculate and to provide third electrical signals representing the initial distribution of defects for the current software program:
said second computer storage storing said third electrical signals: and
a display coupled to said processor and said second computer storage and responsive to said electrical signals for displaying said initial distribution of defects of the current software program.

12. A software defect predictive engine according to claim 11: wherein:
said display is responsive to said electrical signals for displaying a prediction of defects escaping in the current software program.

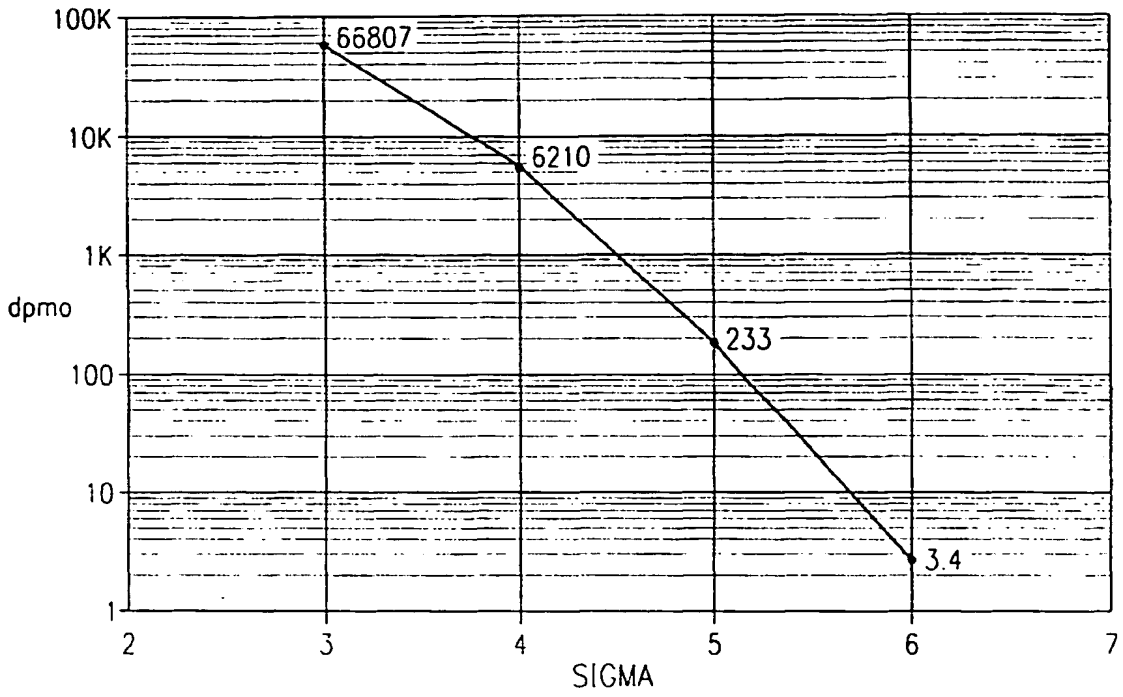


FIG. 1

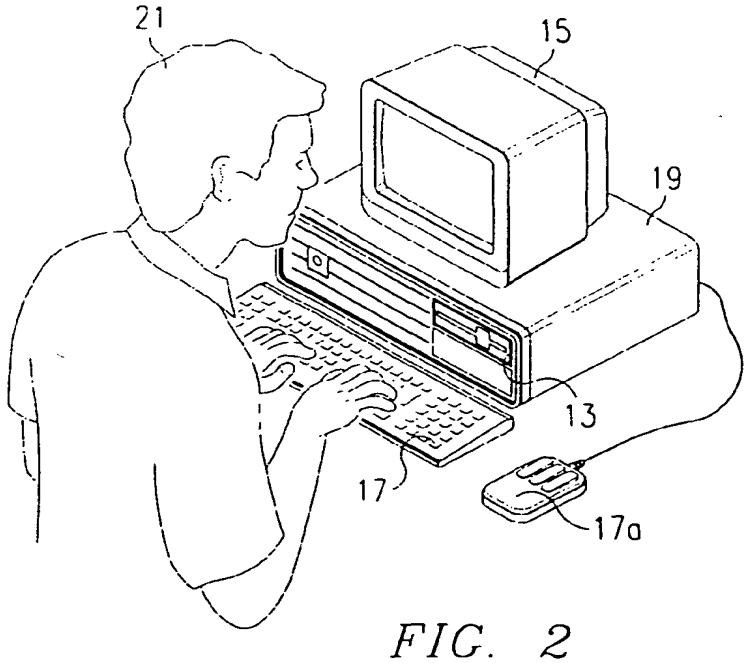


FIG. 2

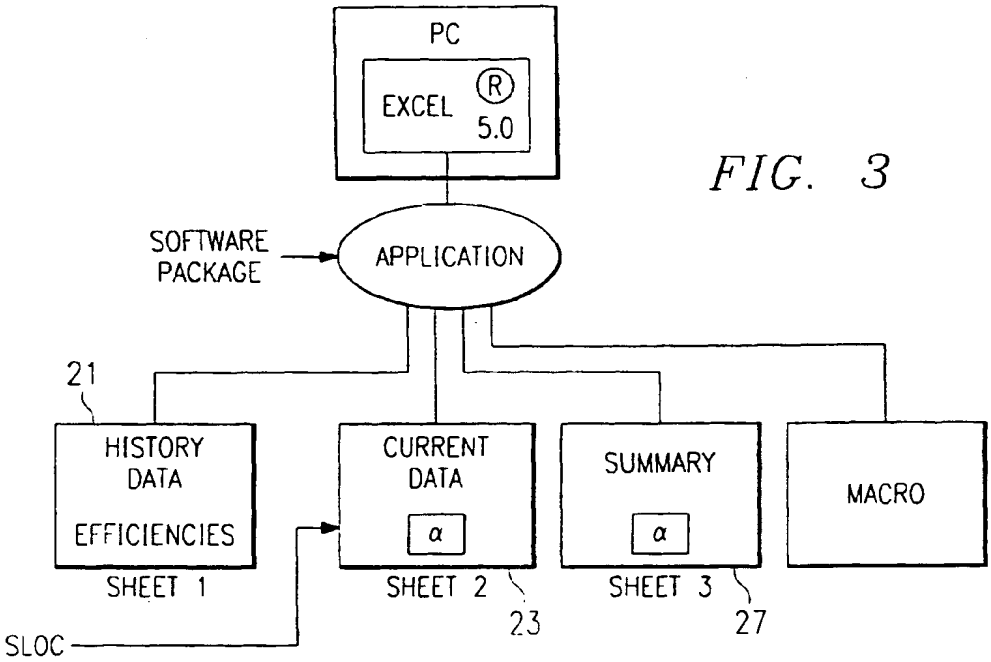


FIG. 3

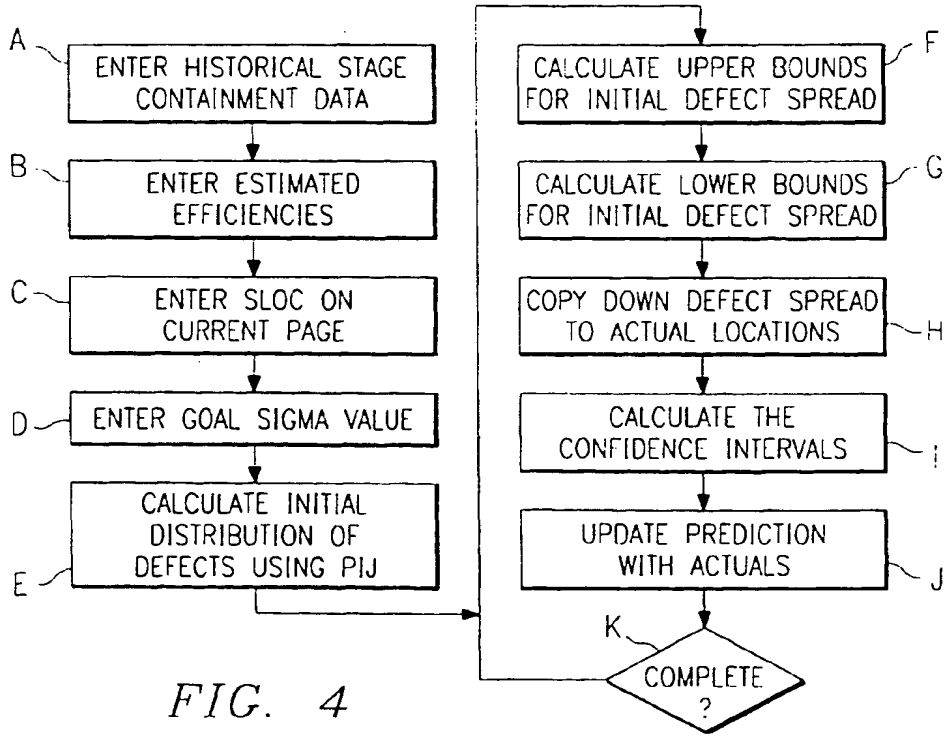


FIG. 4

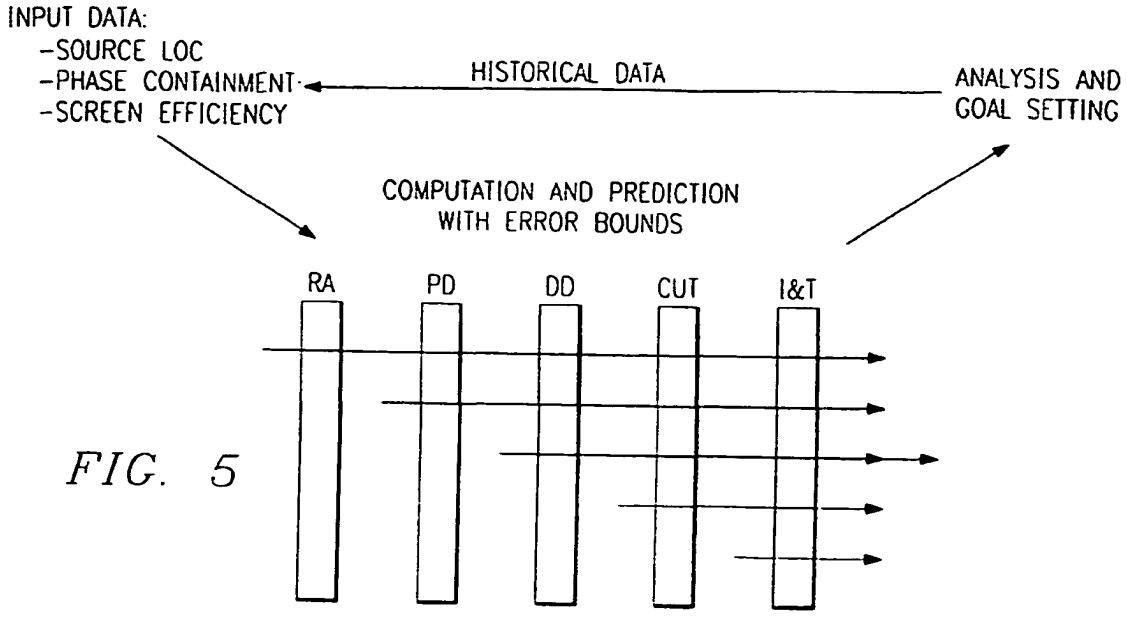
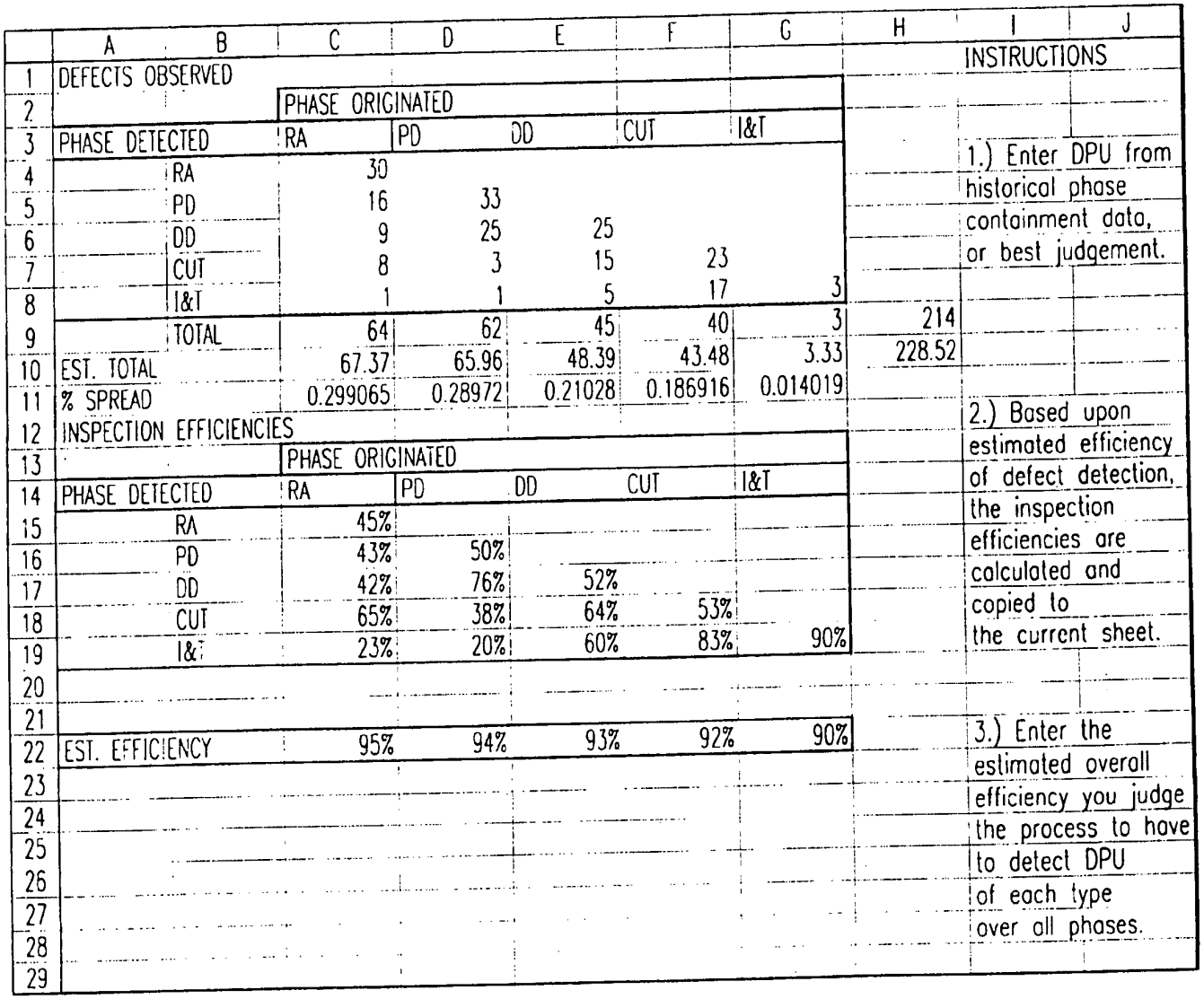


FIG. 5

	A	B	C	D	E	F	G	H	I	J
1				HISTORICAL INPUT						
2										
3	DEFECTS OBSERVED									
4			PHASE ORIGINATED							
5	PHASE DETECTED		RA	PD	DD	CUT	I&T			
6		RA	30	0	0	0	0			
7		PD	6	33	0	0	0			
8		DD	9	25	25	0	0			
9		CUT	8	3	15	23	0	SLOC	50000	
10		I&T	1		5	17	3	SIGMA	4.50	
11										
12	EST. EFFICIENCY		95.00%	94.00%	93.00%	92.00%	90.00%			
13										
14				ACTUAL DATA						
15										
16	DEFECTS OBSERVED									
17			PHASE ORIGINATED							
18	PHASE DETECTED		RA	PD	DD	CUT	I&T			
19		RA	132	0	0	0	0			
20		PD	66	140	0	0	0			
21		DD	36	105	106	0	0	PREDICT		
22		CUT	35	11	62	95	0	SIGMA		
23		I&T	5	5	20	68	12	4.53		
24										
25	EST. EFFICIENCY		94.74%	93.62%	92.47%	91.30%	88.89%			
26										
27				PREDICTIONS						
28										
29	CONFIDENCE LEVELS			CONF.	95%					
30	DPU			opmo		THIS PROGRAM		AVERAGE(SIMILAR)		
31	DPU-UCL		76.50	dopmo-ucl	1530	sigma-ucl	4.62	sigma-ucl	4.55	
32	DPU		60.70	dopmo	1214	sigma	4.53	sigma	4.53	
33	DPU-LCL		44.91	dopmo-icl	898	sigma-icl	4.46	sigma-icl	4.51	
34										

FIG. 8



	A	B	C	D	E	F	G	H	I	J
1	DEFECTS OBSERVED								INSTRUCTIONS	
2			PHASE ORIGINATED							
3	PHASE DETECTED		RA	PD	DD	CUT	I&T			
4		RA	30						1.) Enter DPU from	
5		PD	16	33					historical phase	
6		DD	9	25	25				containment data,	
7		CUT	8	3	15	23			or best judgement.	
8		I&T	1	1	5	17	3			
9		TOTAL	64	62	45	40	3	214		
10	EST. TOTAL		67.37	65.96	48.39	43.48	3.33	228.52		
11	% SPREAD		0.299065	0.28972	0.21028	0.186916	0.014019			
12	INSPECTION EFFICIENCIES								2.) Based upon	
13			PHASE ORIGINATED						estimated efficiency	
14	PHASE DETECTED		RA	PD	DD	CUT	I&T		of defect detection,	
15		RA	45%						the inspection	
16		PD	43%	50%					efficiencies are	
17		DD	42%	76%	52%				calculated and	
18		CUT	65%	38%	64%	53%			copied to	
19		I&T	23%	20%	60%	83%	90%		the current sheet.	
20										
21										
22	EST. EFFICIENCY		95%	94%	93%	92%	90%		3.) Enter the	
23									estimated overall	
24									efficiency you judge	
25									the process to have	
26									to detect DPU	
27									of each type	
28									over all phases.	
29										

FIG. 6

	A	B	C	D	E	F	G	H	I	J
1	DSEG SOFTWARE SIGMA CALCULATIONS					Rel 0.06; May 12, 1995				
2	PART 1--INITIAL VALUES OF		SLOC, PHASE CONTAINMENT			AND SIGMA HISTORY				
3	PRODUCT NAME								INSTRUCTIONS	
4	PRODUCT OPPORTUNITIES		SLOC	50000					1.) Enter SLOC	
5	HISTORICAL SIGMA		SIGMA	4.50					2.) Enter sigma from	
6									historial data or	
7	PHASE PROCESS EFFECTIVENESS (FROM PHASE CONTAINMENT DATA)								fault density of	
8			PHASE ORIGINATED						similar programs.	
9	PHASE DETECTED		RA	PD	DD	CUT	I&T			
10		RA	45%						3.) Go to historical	
11		PD	43%	50%					page and enter data.	
12		DD	42%	76%	52%				The initial phase	
13		CUT	65%	38%	64%	53%			effectiveness is	
14		I&T	23%	20%	60%	83%	90%		computed and	
15	EST. EFFICIENCY		94.74%	93.62%	92.47%	91.30%	88.89%		copied to this page.	
16	PLANNING DPU SPREAD BY PHASE									
17	% SPREAD		30%	29%	21%	19%	1%		4.) Adjust DPU	
18			PHASE ORIGINATED						spread by %.	
19	PHASE DETECTED		RA	PD	DD	CUT	I&T		Initial load copied	
20		RA	142						from historical page.	
21		PD	76	154						
22		DD	43	117	116			Historical	5.) DPU spread	
23		CUT	38	14	69	105		Sigma	agrees with the	
24		I&T	5	5	23	78	13	4.50	initial sigma as	
25		TOTAL	302.42	289.89	208.17	183.05	13.43	996.96	stated in the	
26		Passed	15.92	18.50	15.67	15.92	1.49	67.50	cell to the left.	
27		Generate	318.34	308.39	223.83	198.96	14.92	1064.45		

FIG. 7

FIG. 7 ctd.

28	UPPER										
29	LIMITS		PHASE ORIGINATED					ALPHA_U	6.) Enter upper		
30	PHASE DETECTED	RA	PD	DD	CUT	I&T		0.05	limits alpha_U.		
31	RA	162							There is only an		
32	PD	90	175						alpha_U x 100%		
33	DD	54	135	134					chance that an		
34	CUT	48	20	83	122				actual will exceed		
35	I&T	9	8	31	93	20			the corresponding		
36	TOTAL	363	338	248	215	20		1184	upper limits entry		
37									given true historical		
38	LOWER								assumptions.		
39	LIMITS		PHASE ORIGINATED					ALPHA_L	7.) Enter lower		
40	PHASE DETECTED	RA	PD	DD	CUT	I&T		0.1	limits Alpha_L.		
41	RA	127							There is only an		
42	PD	65	138						Alpha_L x 100%		
43	DD	34	103	102					chance that an		
44	CUT	30	9	59	92				actual will be lower		
45	I&T	2	2	17	67	9			than a corresponding		
46	TOTAL	258	252	178	159	9		856	lower limits entry		
47									given true historical		

FIG. 7 ctd.

48	DEFECTS OBSERVED											assumptions.
49			PHASE ORIGINATED									8.) Enter the actual
50	PHASE DETECTED		RA	PD	DD	CUT	I&T					defects observed
51		RA	132									at end phase.
52		PD	66	140								
53		DD	36	105	106					PREDICT		
54		CUT	35	11	62	95				SIGMA		
55		I&T	5	5	20	68	12			4.53		9.) Predicted sigma.
56		TOTAL	274	261	188	163	12			897.40		
57	ESC. DEFECTS		14.41	16.64	14.15	14.17	1.33			60.70		
58	CONFIDENCE LEVELS			CONF.	95%							10.) CONF. is the
59	DPU		dpmo		THIS PROGRAM		AVERAGE(SIMILAR)					probability that
60	DPU-UCL		76.50	dpmo-ucl	1530	sigma-ucl	4.62	sigma-ucl		4.55		the true dpmo, sigma
61	DPU		60.70	dpmo	1214	sigma	4.53	sigma		4.53		are contained in
62	DPU-LCL		44.91	dpmo-lcl	898	sigma-lcl	4.46	sigma-lcl		4.51		the interval.
63												
64												
65										TOTAL		
66		EST λ+	14.4066	16.63887	14.15054	14.17391	1.333333			60.70325		
67		VAR(EST	0.758242	1.062056	1.065094	1.232514	0.148148			4.266054		
68												

FIG. 9

	A	B	C	D	E	F	G	H	I
1	DSEG SOFTWARE					Rel 0.06; May 12, 19			
2	PART 1-- INITIAL VA			SLOC PHASE			AND SIGMA HISTOR		
3	PRODUCT NAME								INSTRUCTIONS
4	PRODUCT OPPORT		UNITIES	SLOC	50000				1.) Enter SLOC
5	HISTORICAL SIGMA			SIGMA	4.50				2.) Enter sigma from
6									historical data or
7	PHASE PROCESS E								fault density of
8			PHASE ORIGINATED						similar programs.
9	PHASE DETECTED		RA	PD	DD	CUT	I&T		
10		RA	=[MASK16.XL S]HIST						3.) Go to historical
11		PD	=[MASK16.XL S]HIST	=[MASK16.XL S]HIST					page and enter data.
12		DD	=[MASK16.XL S]HIST	=[MASK16.XL S]HIST	=[MASK16.XL S]HIST				The initial phase
13		CUT	=[MASK16.XL S]HIST	=[MASK16.XL S]HIST	=[MASK16.XL S]HIST	=[MASK16.XL S]HIST			effectiveness is

FIG. 9 ctd.

14		I&T	=[MASK16.XLS]HIST	=[MASK16.XLS]HIST	=[MASK16.XLS]HIST	=[MASK16.XLS]HIST	=[MASK16.XLS]HIST		computed and
15	EST. EFFICIENCY		=1-1/C76	=1-1/D76	=1-1/E76	=1-1/F76	=1-1/G76		copied to this page
16	PLANNING DPU SP								
17	% SPREAD		=[MASK16.XLS]HIST	=[MASK16.XLS]HIST	=[MASK16.XLS]HIST	=[MASK16.XLS]HIST	=1-SUM(C17:F17)		4.) Adjust DPU
18			PHASE ORIGINATED						spread by%.
19	PHASE DETECTED		RA	PD	DD	CUT	I&T		Initial load copied
20		RA	=$A$78*$CS17*$CS10						fromhistorical page
21		PD	=(A$78*C$17-CS20)*	=$A$78*$D$17*$D$11					
22		DD	=(A$78*CS17-CS20-C	=(A$78*D$17-D$21)*	=$A$78*$E$17*$E$12			Historical	5.) DPU spread
23		CUT	=(A$78*CS17-CS20-C	=(A$78*D$17-D$21-D	=(A$78*E$17-E$22)*	=$A$78*$F$17*$F$13		Sigma	agrees with the
24		I&T	=(A$78*C$17-CS20-C	=(A$78*D$17-D$21-D	=(A$78*E$17-E$22-E	=(A$78*F$17-F$23)*	=$A$78*$G$17*$G$14	=NORMSINV(1-$H$26	initial sigma as
25		TOTAL	=SUM(C20:C24)	=SUM(D21:D24)	=SUM(E22:E24)	=SUM(F23:F24)	=G24	=SUM(C25:G25)	stated in the
26		Passed	=C25/C76	=D25/D76	=E25/E76	=F25/F76	=G25/G76	=SUM(C26:G26)	cell to the left.
27		Generate	=C25/(A71*C76)	=D25/(A72*D76)	=E25/(A73*E76)	=F25/(A74*F76)	=G25/(A75*G76)	=SUM(C27:G27)	

FIG. 9 ctd.

28	UPPER										
29	LIMITS		PHASE ORIGINATED						ALPHA_U	6.) Enter upper	
30	PHASE DETECTED		RA	PD	DD	CUT	I&T		0.05	limits alpha_U.	
31		RA	=POISSONU L($H$30							There is only an	
32		PD	=POISSONU L($H$30	=POISSONU L($H$30						Alpha_U x 100%	
33		DD	=POISSONU L($H$30	=POISSONU L($H$30	=POISSONU L($H$30					chance that an	
34		CUT	=POISSONU L($H$30	=POISSONU L($H$30	=POISSONU L($H$30	=POISSONU L($H$30				actual will exceed	
35		I&T	=POISSONU L($H$30	=POISSONU L($H$30	=POISSONU L($H$30	=POISSONU L($H$30	=POISSONUL($H$30			the corresponding	
36		TOTAL	=SUM(C31:C 35)	=SUM(D32:D 35)	=SUM(E33:E 35)	=SUM(F34:F3 5)	=G35		=SUM(C36:G3 6)	upper limits entry	
37										given true historical	
38	LOWER									assumptions.	
39	LIMITS		PHASE ORIGINATED						ALPHA_L	7.) Enter lower	
40	PHASE DETECTED		RA	PD	DD	CUT	I&T		0.1	limits Alpha_L.	
41		RA	=POISSONLL ($H$40							There is only an	

FIG. 9 ctd.

42		PD	=POISSONLL ($H$40	=POISSONLL ($H$40						Alpha-L x 100%
43		DD	=POISSONLL ($H$40	=POISSONLL ($H$40	=POISSONLL ($H$40					chance that an
44		CUT	=POISSONLL ($H$40	=POISSONLL ($H$40	=POISSONLL ($H$40	=POISSONLL ($H$40				actual will be lower
45		I&T	=POISSONLL ($H$40	=POISSONLL ($H$40	=POISSONLL ($H$40	=POISSONLL ($H$40	=POISSONLL($H$40			than a corresponding
46		TOTAL	=SUM(C41:C45)	=SUM(D42:D45)	=SUM(E43:E45)	=SUM(F44:F45)	=G45	=SUM(C46:G46)		lower limits entry
47										given true historical
48	DEFECTS OBSERVED									assumptions.
49			PHASE ORIGINATED							8.) Enter the
50	PHASE DETECTED		RA	PD	DD	CUT	I&T			actual defects
51		RA	=$A$78*$C$17*$C$1							observed at end
52		PD	=(A$78*C$17-CS20)*	=$A$78*$D$17*$DS1						of phase.
53		DD	=(A$78*C$17-CS20-C	=(A$78*D$17-D$21)*	=$A$78*$E$17*$E$1				PREDICT	
54		CUT	=(A$78*C$17-CS20-C	=(A$78*D$17-D$21-D	=(A$78*E$17-E$22)*	=$A$78*$F$17*$F$1			SIGMA	
55		I&T	=(A$78*C$17-C$20-C	=(A$78*D$17-D$21-D	=(A$78*E$17-E$22-E	=(A$78*F$17-F$23)*F	=$A$78*$G$17*$G$1	=NORMSINV(1-$H$5		9.) Predicted sigma.

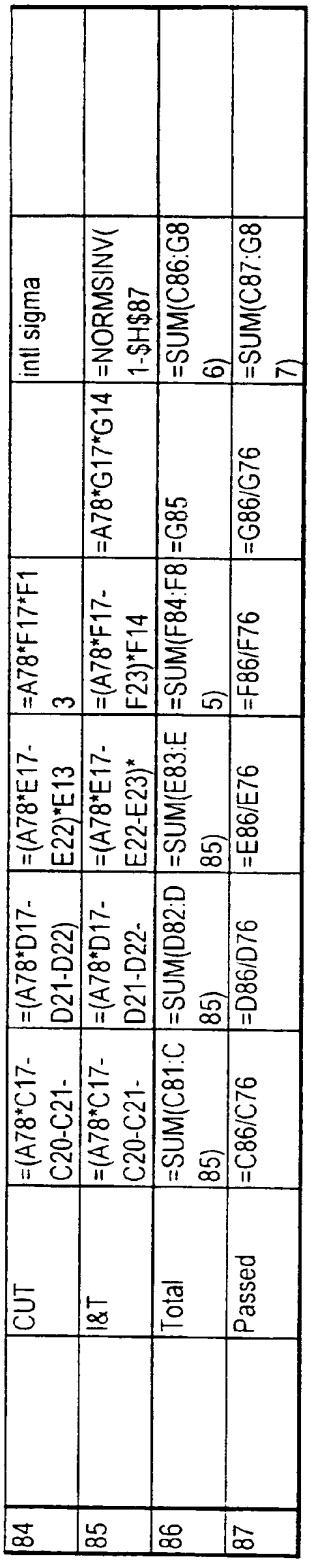
FIG. 9 ctd.

56		TOTAL	=SUM(C51:C55)	=SUM(D52:D55)	=SUM(E53:E55)	=SUM(F54:F55)	=G55	=SUM(C56:G56)	
57	ESC. DEFECTS		=C56/C76	=D56/D76	=E56/E76	=F56/F76	=G56/G76	=SUM(C57:G57)	
58	CONFIDENCE LEVE			CONF.	0.95				10.) CONF. is the probability that
59	DPU		dpmo		THIS PROGRAM		AVERAGE PROGRA(SIMILAR)		the true dpmo,
60	DPU-UCL	=$H$66+NORMSINV	dpmo-ucl	=1000000*B60/$E$4	sigma-ucl	=NORMSINV(1-$B62	sigma-ucl	=NORMSINV(1-(H	sigma are
61	DPU	=H66	dpmo	=1000000*B61/$E$4	sigma	=NORMSINV(1-$B$6	sigma	=NORMSINV(1-$H$5	contained in the
62	DPU-LCL	=$H$66+NORMSINV	dpmo-lcl	=1000000*B62/$E$4	sigma-lcl	=NORMSINV(1-$B$6	sigma-lcl	=NORMSINV(1-(H	interval.
63									
64									
65								TOTAL	
66		EST λ^*	=C56/C76	=D56/D76	=E56/E76	=F56/F76	=G56/G76	=SUM(C66:G66)	
67		VAR(EST λ^*)	=C56/C76^2	=D56/D76^2	=E56/E76^2	=F56/F76^2	=G56/G76^2	=SUM(C67:G67)	
68									
69	A(i)		B(i,j)						

FIG. 9 ctd.

70			RA	PD	DD	CUT	I&T			
71	=(1-$CS10)*(1-$CS11	RA	=(1-$CS10)*(1-$C$11							
72	=(1-$DS11)*(1-$DS12	PD	=(1-$CS11)*(1-$C$12	=(1-$D$11)*(1-$D$12						
73	=(1-$E$12)*(1-$E$13	DD	=(1-$C$12)*(1-$C$13	=(1-$D$12)*(1-$D$13	=(1-$E$12)*(1-$E$13					
74	=(1-$F$13)*(1-$F$14	CUT	=(1-$CS13)*(1-$CS14	=(1-$D$13)*(1-$D$14	=(1-$E$13)*(1-$E$14	=(1-$F$13)*(1-$F$14				
75	=(1-$G$14)	I&T	=(1-$CS14)	=(1-$D$14)	=(1-$E$14)	=(1-$F$14)	=(1-$G$14)			
76		ΣP/B	=C10/C71+C11/C72+	=D11/D72+D12/D73+	=E12/E73+E13/E74+	=F13/F74+F14/F75	=G14/G75			
77	#del/sum aiqi									
78	=($E$4*(1-NORMSD		=A78*(C17*(C10+(1-	=NORMSINV(1-$C$7						
79			PHASE ORIGINATED							
80	PHASE DETECTED		RA	PD	DD	CUT	I&T			
81		RA	=A78*C17*C10							
82		PD	=(A78*C17-C20)*C11	=(A78*D17)*D11						
83		DD	=(A78*C17-C20-C21)	=(A78*D17-D21)*D12	=A78*E17*E12					

FIG. 9 ctd.



84							intl sigma	
85		CUT	=(A78*C17-C20-C21-	=(A78*D17-D21-D22)	=(A78*E17-E22)*E13	=A78*F17*F13	=A78*G17*G14	=NORMSINV(1-$H$87
86		I&T	=(A78*C17-C20-C21-	=(A78*D17-D21-D22-	=(A78*E17-E22-E23)*	=(A78*F17-F23)*F14	=G85	=SUM(C86:G86)
87		Total	=SUM(C81:C85)	=SUM(D82:D85)	=SUM(E83:E85)	=SUM(F84:F85)	=G86/G76	=SUM(C87:G87)
		Passed	=C86/C76	=D86/D76	=E86/E76	=F86/F76		

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 96 30 7828

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	PROCEEDINGS IF THE GLOBAL TELECOMMUNICATIONS CONFERENCE (GLOBECOM), vol. 2, 2 December 1994, SAN FRANCISCO, pages 823-827, XP000488655 ANNA HAC ET AL.: "Improving Reliability of Large Software Systems Through Software Design and Renovation" * page 824, right-hand column, line 4 - page 825, left-hand column, line 8 *	1-3,5,7, 9-12	G06F11/00
Y		4,6,8	

Y	COMPUTER, vol. 27, no. 9, September 1994, LONG BEACH US, pages 18-25, XP000475936 ROBERT B. GRADY: "Successfully Applying Software Metrics" * page 20, left-hand column, line 4 - line 26 *	4,6,8	

			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			G06F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	7 March 1997	Corremans, G

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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